Trans-Pacific HDR Satellite Communications Experiment, Phase-2 Results Summary

Eddie Hsu, Chaw Hung
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA
Phone: +1 818 354-3212, Fax: +1 818 393-3302
eddie.hsu@jpl.nasa.gov

Naoto Kadowaki, Naoko Yoshimura, Takashi Takahashi
Communications Research Laboratory
Ministry of Posts and Telecommunications
Phone: +81 423 27 7513, Fax: +81 423 24 8966
naoto@crl.go.jp

Richard desJardins, Mark Foster, Ray Gilstrap, Larry Chao
National Aeronautics and Space Administration
NASA Research and Education Network
Rdesjardins@mail.arc.nasa.gov

Pat Gary, Paul Lang, Kevin Kranacs
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland
pat.gary@gsfc.nasa.gov

Mike Gill and Haruyuki Tatsumi
National Library of Medicine and
Sapporo Medical University
gillm@mail.nlm.nih.gov

Patrick Shopbell, Gretchen Walker, Dennis Wellnitz
California Institute of Technology and
University of Maryland
pls@astro.caltech.edu

Burt Edelson, Neil Helm, Al Mac Rae
George Washington University
Institute of Applied Space Research
Edelson @seas.gwu.edu

Frank Gargione
[tbd]

ABSTRACT

In 1993, a proposal at the Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP[i]) workshop lead to a subsequent series of satellite communications experiments and demonstrations, under the title *of Trans-Pacific High Data Rate Satellite Communications Experiments.* The first phase of which was a joint collaboration between government and industry teams in the United States and Japan that successfully demonstrated distributed high definition video (HDV) post-production on a global scale using a combination of high data rate satellites and terrestrial fiber optic asynchronous transfer mode (ATM) networks. This was followed by the Phase-2 Internet Protocol (IP) based experiments and demonstrations [4-6] in tele-medicine and distance education, using another combination of two high data rate satellites and terrestrial fiber optic networks.

The *Visible Human* tele-medicine and *Remote Astronomy* distance education demonstrations and their use of distributed systems technologies afforded an opportunity for people around the world to work together as a virtual team under one roof, using resources thousands of miles away as if they were next to each other. The visible human activity demonstrated global-scale interactive biomedical image segmentation, labeling, classification, and indexing using large images; the remote astronomy activity demonstrated collaborative observation and distance education at multiple locations around the globe and the transparent operations of distributed systems technologies over a combination of broadband satellites and terrestrial networks.

The use of Internet Protocol related technologies allowed the general public to be an integral part of the exciting activities, helped to examine issues in constructing a global information infrastructure with broadband satellites, and afforded an opportunity to tap the research results from the (reliable) multicast and distributed systems communities. This paper summarizes the Phase-2 of Trans-Pacific series of experiments and demonstrations by an international team in Canada, Japan, and the United States.

INTRODUCTION

A series of satellite communications experiments and demonstrations involving a combination of broadband satellites and terrestrial fiber optic networks was proposed in the Japan-U.S. Science, Technology and Space Applications Program (JUSTSAP[i]) in 1993. The experiments and demonstrations were initiated in 1996 by

JUSTSAP as part of the G-7 Nations' Information Society - Global Interoperability of Broadband Networks (GIBN) project, with the High Definition Video (HDV) experiment being the first of the series [1-3].

In the United States, the GIBN project was coordinated by the White House National Economic Council, the National Science Foundation, and the National Aeronautics and Space Administration. In Japan, the GIBN project was coordinated by the Ministry of Posts and Telecommunications and the Communications Research Laboratory. And in Canada by the Communications Research Centre (CRC) and by Teleglobe Incorporated.

The experiments and demonstrations are being carried out at various data rates up to OC-3 (155 Mbps), in order to develop and test the transmission techniques and protocols that are needed to incorporate satellite links in high performance global telecommunications networks. The Trans-Pacific series included high definition video, digital library, remote astronomy, tele-medicine, and tele-education and a number of other experiments and demonstrations.

In the HDV experiment, the teams in the United States and Japan demonstrated distributed high definition video (HDV) post-production on a global scale using a combination of high data rate satellites (INTELSAT and NASA ACTS) and terrestrial fiber optic asynchronous transfer mode (ATM) networks. HDV source material was transmitted and composited in real-time between Sony Pictures High Definition Center (SPHDC) in Los Angeles and Sony Visual Communication Center (VCC) in Shinagawa, Tokyo, demonstrating that satellites can deliver digital image traffic at data rates up to OC-3 and with quality comparable to that of fiber optic cables [2,3].

This was followed by Internet Protocol (IP) based experiments and demonstrations [4-6] in tele-medicine and distance-education using a combination of terrestrial fiber optic networks and two high data rate geostationary satellites for a total signal path exceeding 100,000 miles across Canada, Japan, and the United States. The use of IP based technology facilitated the participation of students and even general users in the exciting international activities of using satellite communications in the global information infrastructure [7,9]. And it helped examine issues in constructing a global information infrastructure involving high data rate satellites, and would provide an opportunity in applying cutting edge research results from reliable multicast and distributed systems communities.

THE PHASE-2 ACTIVITIES

The Phase 2 demonstrations in Year 2000 included Visible Human and Remote Astronomy. The tele-medicine, or *Visible Human* demonstration, used the network to conduct remote, collaborative medical processes between the National Library of Medicine (NLM) of the United States National Institute of Health (NIH) in Bethesda, Maryland, and the Sapporo Medical University (SMU) in Sapporo, Japan. The *Remote Astronomy* demonstration afforded students hands-on ability to control a remote telescope located at the Mt. Wilson Observatory, California, simultaneously from their classrooms in Japan and across the United States.

Visible Human

The Visible Human tele-medicine demonstration showed a distributed application model enabling interactive biomedical image segmentation, labeling, classification, and indexing to take place over large images on a global scale. It involved a digital image library of volumetric data representing a complete, normal adult male and female cadaver (*The Visible Human Project*) currently residing at the NLM in Maryland. The thinly sliced images in the dataset are of cryosections derived from computerized tomography and magnetic resonance. Due to the size and international importance of the dataset, multilingual labeling of the dataset was proposed. The model facilitated multi-lingual access to the dataset through interactive *whiteboard* medical-image-based consultation, with multi-lingual assistance for collaborative work between medical researchers in different countries. Available global-scale high speed access to an anatomical segmented human anatomy atlas would be a vital resource for biomedical researchers worldwide.

The demonstration involved software tools to show sections of a human body, and enabled a researcher to make an interactive 3-dimensional segmentation in order to recognize each anatomical object. Also, it calculated and filled areas in the segment and rendered them in a distributed manner. This would be followed by the attachment of anatomical terms to the objects working with the NLM's Unified Medical Language System and creating a multilingual object database. Visible human data would then be transferred to and from the researcher world-wide over a high performance network. Processing of large dataset would be expedited and simplified with available computational resources at various locations. Transmission Control Protocol (TCP) gateways for communication over satellites were also installed on both sides of the Pacific to enhance transmission performance over the satellite links.

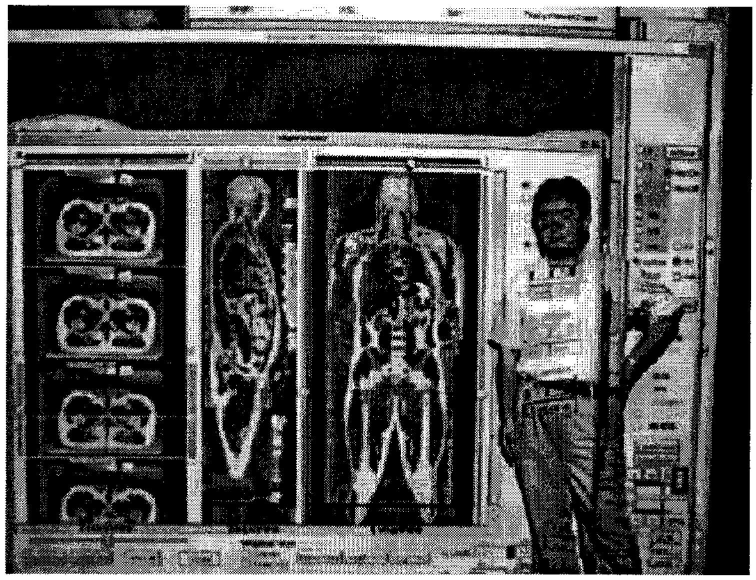

Figure 1 – Visible Human Distributed Application Demonstration.

Remote Astronomy

The Remote Astronomy tele-education demonstration created a wide-area environment for distance learning and collaborative discussions/observations using IP based teleconference (H.323 and multicast) and AFS distributed file system technologies. The remote astronomy system helped bring a remotely controlled telescope and charge-coupled device camera in a real-time, hands-on, interactive environment to students and even the general public around the world. And it demonstrated the transparent operation of distributed systems technologies over a network consisting of broadband satellites and terrestrial fiber optic networks.

The remote astronomy sessions consisted of global-scale joint observations, distributed image access, and instruction sessions from an astronomer in Pasadena to students located in Japan and the United States. Instructors from Soka High School and astronomers from the California Institute of Technology, Mt. Wilson Institute, and the University of Maryland also participated. Observation sessions would start at 9 p.m. on the United States West coast with other participants in the United States and Japan logging into both the videoconference server and the Mt. Wilson telescope server at the beginning of the session. Students in Japan would be participating in the afternoons in Tokyo. The astronomer in Pasadena would then lead lectures and observations with themes such as the structures of galaxies, lives of stars, and where are all the stars.

Students and other participants in the US and Japan were asked to control the telescope in turn, and the images acquired by the controlling site were distributed via AFS distributed file system to all other participants. Images from the Hubble Space Telescope archive images were also used to compare and contrast with those taken with the Mt. Wilson telescope. All participants were able to observe each other's activities as if all were sitting in one room. It would be possible for one site to be responsible for taking pictures, while others carrying out image processing on the pictures taken, with results for all participants to see.

For the Phase 2 IP-based demonstrations, the large bandwidth delay product of the satellite links on TCP were mitigated by the use of special performance-enhancing gateways. The use of distributed storage systems and local processing would also help enhance communication performance in increasing the amount of useful data returned. For applications that are not accelerated by the gateways, such as distributed file systems, they would experience lower throughput over satellite links if the parameters were not suitably tuned to reflect the broadband links. Many of these performance issues in distributed systems were similar to the well publicized

TCP-over-satellite issues on window sizes, timer settings, loss recovery mechanisms, and acknowledgement schemes.

Therefore, it is important to consider at onset the characteristics of emerging high speed, long distance networks on protocol mechanisms and their designs in all types of communications and distributed systems. Perhaps an evolution path should be defined early on to facilitate the future integration of such networks.

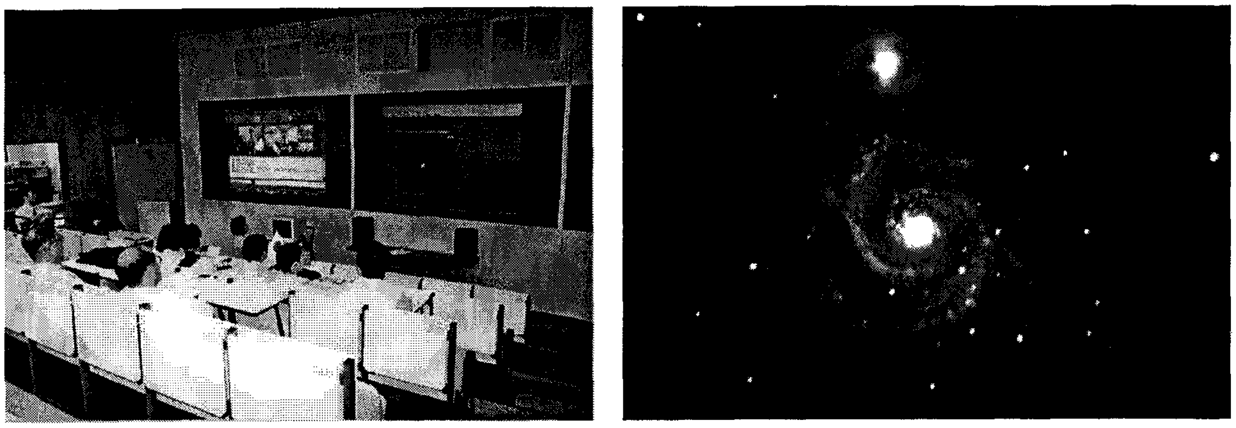

Figure 2 – Remote Astronomy Demonstration.

THE NETWORK INFRASTRUCTURE

The experimental network was configured as shown in Figure 3. Japan and the North America were connected via INTELSAT 802 located at the geostationary orbit 174°E. The gateways to the trans-Pacific link are the Lake Cowichan earth station (LCW) of Teleglobe Canada and the Kashima Space Research Center (KSRC) earth station of the Communications Research Laboratory (CRL). The North American participants were connected to LCW using terrestrial networks via Canada's Metronet, BCNet and CA*NET3; the U.S. based NASA Research and Education Network (NREN), NASA Integrated Service Network (NISN) and ATD-Net; and in Japan, the link was extended to CRL Headquarters (CRL-HQ) via CRL's private OC-48 fiber optic link from KSRC, and to the Sapporo Medical University (SMU) via the JSAT N-STAR-a satellite.

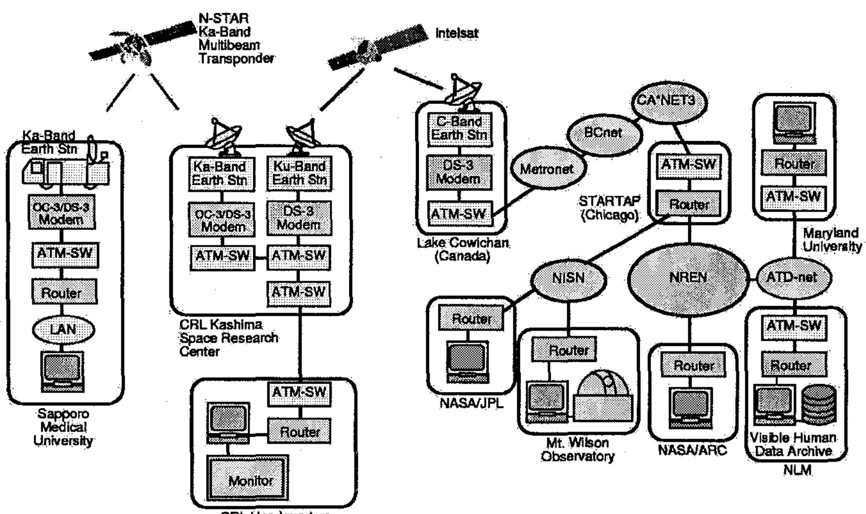

Figure 3 Trans-Pacific Network Diagram.

Both the remote astronomy and the visible human demonstrations ran concurrently over much of the same network infrastructure. The remote astronomy demonstration was conducted on the connection between CRL-HQ, NASA/ARC, NASA-JPL, the Mt. Wilson Observatory, Keck Math and Science Institute (KMSI) of the

Crossroads High School (Santa Monica, CA), and the University of Maryland, College Park. The visible human demonstration was conducted on the connection between SMU, NASA/ARC, NASA/GSFC, and NLM. NREN played an instrumental role as the infrastructure management center for demonstrations during the Phase-2 experiments.

THE INTELSAT LINK

The team originally planned on OC-3 (155 Mbps) transmissions across the Pacific and SDM-155 modems were readied for placement. However, due to customer preemption, the team had finally obtained 28.17 MHz on INTELSAT 802. CRL and Teleglobe used SDM-9000 modems utilizing 8PSK modulation with rate 5/6 Trellis coding to meet the allocated bandwidth of 28.17 MHz for DS-3 (45 Mbps) level transmissions.

The transmission signal from KSRC has the bandwidth of 23.5 MHz in 99% power occupying bandwidth. But the transmitted signal's bandwidth of the satellite transponder was measured as full of the allocated one through the INTELSAT's Satellite System Operation Guide (SSOG) test during May 24 to 26, 2000 (JST). It meant that the signal's bandwidth became a little bit wider due to transponders nonlinearity. This effect appeared very frequently in satellite communications. But CRL's transmission does not affect any other customers' communication because the transponder was less utilized from Japan to Canada. In the reverse direction, however, the transponder was near full utilization and the edge of the carrier overlapped on neighboring carriers. Interference was noticed and later the carrier frequency was shifted 3 MHz higher to avoid the situation.

THE N-STAR-A LINK

CRL used Ka-band Earth station located at KSRC and a transportable earth station to establish the N-STAR-a link to SMU. The transponder has the bandwidth of 200 MHz and rates up to OC-3 (155 Mbps) were possible with the transponder. The transportable earth station was installed at SMU in January, 2000, and was ready after link quality tests conducted in February and March. The modulation scheme of QPSK R3/4 and RS(108,192) were used for the link during demonstrations.

TERRESTRIAL AND UNDERSEA LINKS

The wide-area terrestrial network service was provided by NASA Research and Education Network, NASA Integrated Services Network, ATD-Net, Teleglobe (Canada and U.S.), AT&T Canada (formerly Metronet), CA*Net3 (Canada), and IMNet. A parallel path via the undersea Asia-Pacific Advanced Network (APAN) was also established. The undersea link served as an alternative route before and after the satellite link was established.

OUTCOME

In the visible human tele-medicine demonstration, the high performance infrastructure facilitated the distributed processing of the large dataset (40 Gbytes female, 15 Gbytes male). The global-scale connectivity allowed medical researchers around the world to work together in processing a dataset of international importance. The system permitted the 3-dimensional segmentation and labeling of human anatomical objects using Unified Medical Language in multiple languages. The high speed afforded by the infrastructure helped reduced the processing time from 3 minutes per image-slice down to 10 seconds, and the time savings over the entire dataset becomes large. The effects of delays were readily mitigated by special gateways, such as SkyX, Figure 4, over 14-hop connections.

In the remote astronomy application, the global scale infrastructure permitted students around the world to interact in astronomical observations via video conferencing and multi-party telescope control software. Such a network would also permit continuous tracking of important celestial objects or events around the clock via an array of telescopes. In conventional astronomy, an observer would have to wait until night time to make observations. The trans-Pacific infrastructure permitted students in Japan to access telescopes in the United States during day-time classroom hours. The use of distributed file system allowed the images taken by the telescope to be disseminated to all participating sites transparently, without human intervention. When one location takes pictures of objects in the sky, the other can conduct additional processing of the images taken. The results and changes would be synchronized across the entire distributed file system automatically.

Some of the limitations encountered in using the Internet Protocol technologies, particularly with an emphasis on involving students and even the general public, is that some of the software used were designed for the more limited capabilities of the home personal computers. This contrasted with the equipment used in the Phase-1 HDV experiment [1-3].
How quickly the more advanced equipment and technologies could move into the homes of general users and the rate at which emerging research results could be deployed on a global scale would most likely depend upon suitable business cases. And it would undoubted be expedited if research and other large organizations could start making use of them in their daily operations.

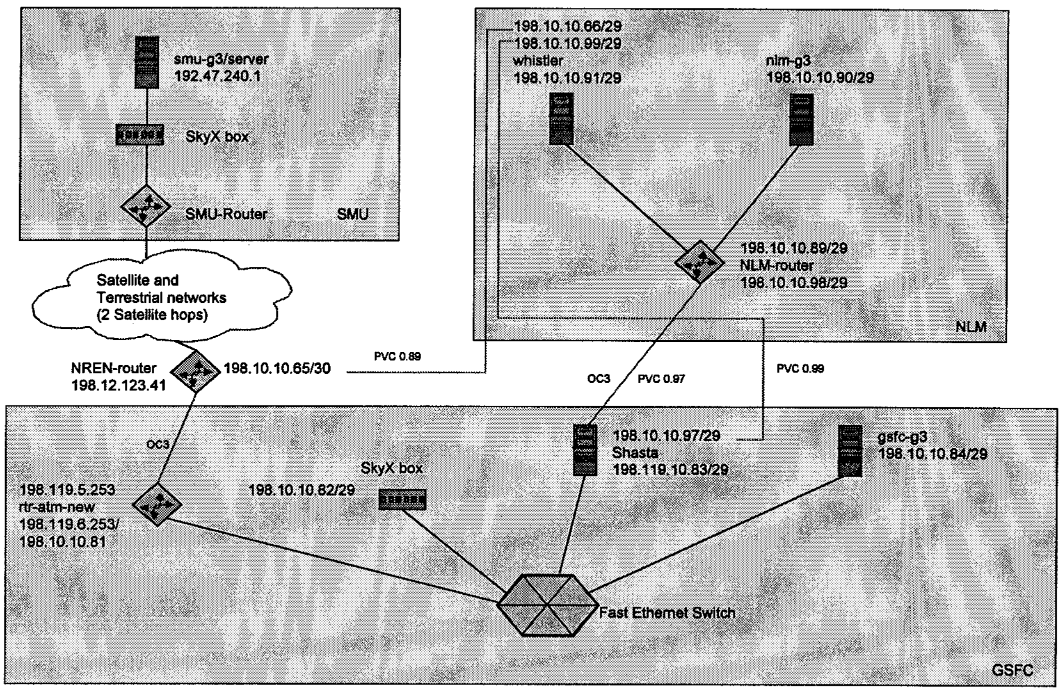

Figure 4 SkyX Gateway Configuration for visible human tele-medicine processing.

8. CONCLUSION

In 1993, a proposal at the Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP) workshop, organized by the State of Hawaii, lead to a subsequent series of satellite communications experiments and demonstrations, under the title *of Trans-Pacific High Data Rate Satellite Communications Experiments.* These experiments and demonstrations, initiated in 1996, have helped explore and develop satellite transmission techniques, standards, and protocols in order to determine how best to incorporate satellite links with fiber optic cables to form high performance global telecommunications networks. These activities help validate emerging technologies and service models in a global information infrastructure, and can span to include activities in global-scale virtual presence, solar system internetwork, disasters mitigation, and other high data rate, distributed applications.

As people, organizations, and resources become more distributed and mobile in nature, a global information infrastructure involving broadband satellites serves to bridge wide geographical distances and make information and equipment resources available to anyone, anywhere, at anytime. In such an environment, the ability to effectively share resources and capabilities in a distributed manner becomes important, and the distinction between communications networks and distributed systems becomes less clear. The Phase-2 series of the experiments helped examine the use of Internet Protocol based technologies in a global scale information infrastructure involving multiple high data rate satellites at rates up to OC-3 (155 Mbps), and were studied in the context of a globally distributed systems environment.

The rate at which emerging research results could be deployed on a global scale would most likely depend upon suitable business cases, and would undoubted be expedited if research and other large organizations could start making use of them in their daily operations. The team is currently planning the Phase-3 activities under the Trans-Pacific series, and is considering establishing a more permanent infrastructure.

PARTICIPANTS IN PHASES ONE AND TWO OF THE EXPERIMENTS

The Canadian participants included AT&T Canada, BCnet, CANARIE, Communications Research Centre (CRC), and Teleglobe Inc. The Japanese participants included Communications Research Laboratory (CRL), Institute of Space and Astronautical Science, Japan Ministry of Posts and Telecommunications (MPT), JSAT Corporation, Inter-Ministry Research Information Network (IMNet), Japan Gigabit Network, Kokusai Denshin Denwa Company, Limited (KDD), Mitsubishi Electric Corporation, Nippon Telegraph and Telephone Corporation (NTT), NTT Communications, Sapporo Medical University, Soka High School, and Sony Corporation. The U.S. participants Apple Federal Systems, ATDNet, AverStar Inc., California Institute of Technology, Comsat, Crossroads High School, George Washington University, GTE Hawaiian Tel, Lockheed Martin, Mentat Inc., Mt. Wilson Institute, NASA Glenn Research Center, NASA Goddard Space Flight Center, NASA Headquarters, NASA Integrated Services Network, NASA Jet Propulsion Laboratory, NASA Research and Education Network, National Library of Medicine/National Institute of Health, National Science Foundation, Newbridge Networks Inc., Pacific Bell/CalREN, Pacific Space Center, Sony Pictures High Definition Center, State of Hawaii, Teleglobe USA, Thomas Jefferson High School, Tripler Army Medical Center, and University of Maryland. International organizations, Asia-Pacific Advanced Network (APAN), INTELSAT, and Science, Technology and Research Transit Access Point (STAR-TAP) also participated.

The capabilities afforded by an emerging global scale broadband information infrastructure emphasize the distributed nature of today's information systems. One such example is the interplentary network. These systems bring with it issues of scale, heterogeneity, robustness, and interoperability, and compose part of the questions the team will help address.

9. ACKNOWLEDGEMENT

The activities described in this paper were carried out jointly by the participants mentioned. The successful outcome would not have been possible without the close cooperation of the involved academic, industry and government organizations. It is the authors' privilege to describe in this paper the effort by every member of the international team. And many thanks to the State of Hawaii for organizing the Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP), through which the international collaboration became a reality.

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[i] Formerly named the Japan-U.S. Cooperation in Space Program. The program is officially sponsored by the State of Hawaii.